

**M e m o r a n d u m**

To: Marley Hart, Executive Officer  
Occupational Safety and Health Standards board  
2529 Venture Oaks Way, Suite 350  
Sacramento, CA 95818

May 8, 2012

**RECEIVED**

From: Ellen Widess, Chief *EWidess*  
Department of Industrial Relations  
Division of Occupational Safety and Health

**MAY 11 2012****OCCUPATIONAL SAFETY AND HEALTH  
STANDARDS BOARD**

Subject: Petition 527 – Truck Seat Vibration Induced Injury

Dear Ms. Hart;

This letter documents the Division of Occupational Safety and Health findings and position in regard to Petition 527, submitted by Mr. Aaron Crane (Petitioner), requesting that the Occupational Safety and Health Standards Board adopt standards to regulate the vibration operator seats in heavy trucks of the type typically used in over-the-road heavy haul operations (semi tractor-trailer trucks)<sup>1</sup>.

**Background**

The petitioner is a truck driver who states that he has experienced low back pain/injury that he attributes to exposure to intense vibration over long periods of driving heavy trucks in what we understand to be over-the-road trucking operations. There is a substantial body of research that supports the relationship between back injuries and extended hours of truck driving. Whole body vibration (WBV) and impact shock exposures are common, as is the accompanying complaint of low back pain among heavy truck drivers.

**Existing Regulation**

No state or federal occupational safety and health regulations, or federal motor vehicle safety standards, identified speak to seating design to mitigate hazards to employees that may result from vibration or impact associated with driving motor vehicles<sup>2</sup>.

Although there are studies linking truck vibration with causation of vehicle accidents and regulations that address construction and maintenance of private roads, the Division has found no Occupational Safety and Health regulations, State or Federal, that are directly on point for dealing with the issue of injuries to vehicle operators resulting from WBV and frequent impact shocks transmitted from heavy trucks during operation, via operator seats. Title 8 of the California Code of Regulations has regulatory provisions for dealing with roadway conditions on private roads, but has no jurisdiction with respect to the condition of public roadways.

The Federal Motor Vehicle Safety Standards, found in Title 49 of the Code of Federal Regulations, address requirements for seat anchorage and seat belts, however they contain no rules or guidance with respect to seat design for control of WBV exposures.

<sup>1</sup> See Attachment no. 1: Occupational Safety and Health Standards Board – Petition No. 527

<sup>2</sup> See Attachment No. 2: Regulations Applicable to Trucking/Haulage Vehicle Operations

## **Analysis**

The consequences of exposures to WBV have been long recognized. The effects of WBV have been shown to vary with vibration frequency (Hertz), amplitude (acceleration), and duration of exposure<sup>3</sup>. Health effects attributed to WBV include: abdominal pain, headaches, chest pain, nausea, loss of equilibrium, decreased performance in precise manipulation tasks, shortness of breath, influence on speech, degenerative spinal disorders, herniated discs, intervertebral disc disease, lumbar scoliosis, disorders of the gastrointestinal system, and uro-genital systems<sup>4</sup>. Engineering studies have shown conclusively that truck drivers are often subjected to WBV and impact shocks that exceed established norms for human body tolerances, and that these exposures have resulted in injury to many of these workers.

Accidents have been attributed to vehicle vibration, and impact shocks. Long-term exposure to vibration has been shown to reduce operator response due in significant part to fatigue induced degradation of manual proficiency. Foam cushions, air cushions, and conventional air-ride seating systems have not proven effective in reducing WBV exposures in long-term applications. Operator seating systems that are rapidly responsive to wide variations in vehicle forces transmitted to the operator through the seat may help reduce the overall number of truck accidents that result from loss of operator control. These benefits can be provided by magneto-rheological elastomers and magneto-rheological fluid shock/vibration dampening seat suspension systems, and other proprietary seating systems available today<sup>5</sup>.

Title 8 Section 5110 for the control of Repetitive Motion Injuries may be construed as having application in evaluation and remediation of WBV exposures if the Division has jurisdiction. However, this has not been tried up till now, and 8 CCR 5110 may be found inapplicable on a jurisdictional basis.

It is not clear that the State has authority to exercise jurisdiction over the seating provided in over-the-road trucks. Given that the US Department of Transportation has enacted some rules applicable to truck seating and operator safety, it is unlikely that the Division could exercise jurisdiction for the affected workers whose occupations are subject of interstate commerce and regulated by the US Department of Transportation.

## **Recommendation**

The Division believes that there is a significant hazard to truckers from WBV and there are technologies available to reduce the risk of injuries. However, the Division is concerned that it would not have jurisdiction to enforce such a standard if it were adopted.

If there are additional questions regarding this subject please contact Cal/OSHA Research and Standards Safety Unit at (510) 286-7000.

File: Petition 527

<sup>3</sup> See Attachment No. 3: ILO Encyclopedia of Occ. Health and Safety, 4<sup>th</sup> Ed., Chapter. 50, Figures 50.1 and 50.2

<sup>4</sup> See Attachments No. 3 and No. 4: ILO Encyclopedia of Occ. Health and Safety, Chptr 50, Whole Body Vibration; Occupational Health Clinics for Ontario Workers Inc. - Whole Body Vibration

<sup>5</sup> See Attachment No. 5: The elastic and damping properties of magnetorheological elastomers; Marke Kallio, Copyright © VTT Technical Research Centre of Finland 2005

Attachment No. 1

Occupational Safety and Health Standards Board – Petition No. 527

Petition to adopt Regulations addressing Operator Exposure to Whole Body Vibration in  
Haulage Vehicle/Heavy-Truck Operations


Aaron Crane - Petitioner

State of California  
Department of Industrial Relations

## Memorandum

**To :** Ellen Widess, Chief, DOSH  
Division of Occupational Safety and Health  
1515 Clay Street, Suite 1901  
Oakland, California 94612

**Date:** February 7, 2012

**From :**  Occupational Safety and Health Standards Board  
Marley Hart, Executive Officer

**Subject:** Aaron Crane, Petition File No. 527

Attached is a petition submitted by Aaron Crane. Mr. Crane is petitioning the Occupational Safety and Health Standards Board with regard to a whole body vibration quotient for truck drivers.

As you are aware, any interested person may propose new or revised standards to the Standards Board and the Board is required to consider such proposed standard(s) and report its decision no later than six months following receipt of such proposal (Labor Code Section 142.2).

Labor Code Section 147 requires the Division to submit its evaluation report on petitions within 60 days of the Division's receipt of the petition. Your report, therefore, will be due approximately April 3, 2012.

Following receipt of the Division's evaluation report, this matter will be scheduled for consideration by the Board at one of the future Business Meetings.

Should you have any questions regarding this matter, please give me a call at (916) 274-5721.

Attachment

cc: Christine Baker, Director

**RECEIVED**

**FEB 10 2012**

Division of Occupational Safety & Health  
Headquarters Office

Hart, Marley@DIR

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From: N B [nbulk@yahoo.com]  
Sent: Tuesday, January 31, 2012 3:10 AM  
To: Hart, Marley@DIR  
Subject: Re: Petition Request

Hi Marley,

Yes, this is correct.

Here are a few studies that I hope will clarify the scientific basis for my concern. This way you aren't just taking my word for it, although my testimony is that my back hurt so bad that I would wake up and not be able to breathe. This was just after driving for one year 12 hours a day 60 hours a week, and only being 25 years of age and very fit and otherwise healthy. My step dad suffered the same symptoms, and he was a truck driver as well, for many years. From what I've read many other truck driver's also suffer back pain.

<http://oem.bmj.com/content/early/2008/01/23/oem.2007.035147.abstract>

<http://pih.sagepub.com/content/213/6/435.abstract>

<http://wholebodyvibration.org/Railroad%20Research%20Articles2.htm#Journal%20of%20Occupational%20Medicine/Volume%2033%20No.%205/May%201991>

<http://www.ncbi.nlm.nih.gov/pubmed/21698878>

and there are many many more studies.

It appears that the UK has regulations regarding this already in place

<http://www.hse.gov.uk/vibration/wbv/regulations.htm>

I'm proposing regulations be set forth here in California so that more truck drivers need not suffer the pain of lower back aches. This is costly, as it leads to lower productivity, days missed from working, increased medical costs and lower overall morale.

Thanks for your help.

Should you require any further assistance from me, please don't hesitate to ask.

Sincerely,

Aaron Crane

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From: "Hart, Marley@DIR" <MHart@dir.ca.gov>  
To: "nbulk@yahoo.com" <nbulk@yahoo.com>  
Sent: Monday, December 19, 2011 9:59 AM  
Subject: Petition Request

Mr. Crane,

On Thursday, December 15, 2011, I received a telephone call from you, requesting the Occupational Safety and Health Standards Board to create a new regulation that would impact truck drivers. You would like a whole body vibration quotient for truck drivers, which would state how much vibration would be allowed in the cab of a truck for an 8 hour driving period.

Your information is as follows:

Attachment No. 2

Regulations Applicable to Trucking/Haulage Vehicle Operations

**Title 8 California Code of Regulation - Construction Safety Orders, General Industry Safety Orders, Logging Safety Orders, Mining Safety Orders, Tunnel Safety Orders**

Section 1590 of Title 8 Construction Safety Orders requires that private haul roads shall be maintained free of holes and ruts that affect safe operation of haulage vehicles. This section also contains a requirement for dust control to prevent hazards related to visibility. Section 1593 of Title 8 Construction Safety Orders contains prohibitions on excessive speed, requirements for load stability and operator visibility, and a requirement for inspection of seatbelts.

Section 3702 of the General Industry Safety Orders provides that vehicles used regularly for transportation of workers shall be equipped with seats that are adequately secured and that seat belts must be provided for each seat. Only minimal specifications are given for the seat design or construction.

Section 6265 and 6266 of Title 8 Logging Safety Orders address safety of logging roads and bridges. These sections require that roadways and bridges are to be constructed in a manner to minimize hazards of truck operation, and require that logging roads and bridges be maintain free of conditions that are hazardous to operation of logging trucks. These regulations do not speak to control of vibration or shock hazards that result from truck operator seats.

Section 7014 of Title 8 Mining Safety Orders contains requirements for construction and maintenance of private roads. Section 7016 of these orders requires that haulage vehicle seats shall be maintained in good repair at all times. Sections 7010 and 7021 contain specific rules applicable to safe operation of mine haulage vehicles.

Sections 8483 and 8484 of the Tunnel Safety Orders address operation of haulage vehicles and private roadways respectively. Among the various rules applicable to operation of haulage vehicles is a requirement that the driver's seat shall be maintained in good condition. Section 8484 provides for maintenance of private roadways in accordance with the regulations of Construction Safety Orders Section 1590, and further specifies that roadways shall be maintained free of holes, ruts, and standing water.

**Title 29, Code of Federal Regulation, Part 1910 - General Industry Safety Regulations**

Section 1910.266(f) and (g) contain limited provisions for providing seating for operators and passengers in logging operations, but do not address seating design to deal with issues of vibration or impact.

**Title 29, Code of Federal Regulation, Part 1926 - Construction Safety Regulations**

29 CFR 1926.601 of the Federal Construction Safety Regulations requires that seating that is securely anchored to the vehicle and in adequate number shall be provided for vehicles used for transportation of employees. This section also requires that seat belts meeting the requirements of 49 CFR 571 are to be provided in all motor vehicles.

**Attachment No. 3**

**ILO Encyclopedia of Occupational Health and Safety, 4th Edition**

**Chapter 50 - Whole Body Vibration**

## WHOLE-BODY VIBRATION

Helmut Seidel, Michael J. Griffin

### Occupational Exposure

Occupational exposures to whole-body vibration mainly occur in transport but also in association with some industrial processes. Land, sea and air transport can all produce vibration that can cause discomfort, interfere with activities or cause injury. Table 50.1 lists some environments which may be most likely to be associated with a health risk.

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*Table 50.1 Activities for which it may be appropriate to warn of the adverse effects of whole-body vibration*

Tractor driving  
Armoured fighting vehicles (e.g., tanks) and similar vehicles  
Other off-road vehicles:  
· Earth-moving machinery-loaders, excavators, bulldozers, graders, scrapers, dumpers, rollers  
· Forest machines  
· Mine and quarry equipment  
· Forklift trucks  
Some truck driving (articulated and non-articulated)  
Some bus and tram driving  
Some helicopter and fixed-wing aircraft flying  
Some workers with concrete production machinery  
Some railway drivers  
Some use of high-speed marine craft  
Some motor bicycle riding  
Some car and van driving  
Some sports activities  
Some other industrial equipment

Source: Adapted from Griffin 1990.

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The most common exposure to severe vibration and shocks may occur on off-road vehicles, including earth moving machinery, industrial trucks and agricultural tractors.

### Biodynamics

Like all mechanical structures, the human body has resonance frequencies where the body exhibits a maximum mechanical response. Human responses to vibration cannot be explained solely in terms of a single resonance frequency. There are many resonances in the body, and the resonance frequencies vary among people and with posture. Two mechanical responses of the body are often used to describe the manner in which vibration causes the body to move: *transmissibility* and *impedance*.

The transmissibility shows the fraction of the vibration which is transmitted from, say, the seat to the head. The transmissibility of the body is highly dependent on vibration frequency, vibration axis and body posture. Vertical vibration on a seat causes vibration in several axes at the head; for vertical head motion, the transmissibility tends to be greatest in the approximate range of 3 to 10 Hz.

The mechanical impedance of the body shows the force that is required to make the body move at each frequency. Although the impedance depends on body mass, the vertical impedance of the human body usually shows a resonance at about 5 Hz. The mechanical impedance of the body, including this resonance, has a large effect on the manner in which vibration is transmitted through seats.

### Acute Effects

#### **Discomfort**

The discomfort caused by vibration acceleration depends on the vibration frequency, the vibration direction, the point of contact with the body, and the duration of vibration exposure. For vertical vibration of seated persons, the vibration discomfort caused by any frequency increases in proportion to the vibration magnitude: a halving of the vibration will tend to halve the vibration discomfort.

The discomfort produced by vibration may be predicted by the use of appropriate frequency weightings (see below) and described by a semantic scale of discomfort. There are no useful limits for vibration discomfort: the acceptable discomfort varies from one environment to another.

Acceptable magnitudes of vibration in buildings are close to vibration perception thresholds. The effects on humans of vibration in buildings are assumed to depend on the use of the building in addition to the vibration frequency, direction and duration.

Guidance on the evaluation of building vibration is given in various standards such as British Standard 6472 (1992) which defines a procedure for the evaluation of both vibration and shock in buildings.

### ***Activity interference***

Vibration can impair the acquisition of information (e.g., by the eyes), the output of information (e.g., by hand or foot movements) or the complex central processes that relate input to output (e.g., learning, memory, decision-making). The greatest effects of whole-body vibration are on input processes (mainly vision) and output processes (mainly continuous hand control).

Effects of vibration on vision and manual control are primarily caused by the movement of the affected part of the body (i.e., eye or hand). The effects may be decreased by reducing the transmission of vibration to the eye or to the hand, or by making the task less susceptible to disturbance (e.g., increasing the size of a display or reducing the sensitivity of a control). Often, the effects of vibration on vision and manual control can be much reduced by redesign of the task.

Simple cognitive tasks (e.g., simple reaction time) appear to be unaffected by vibration, other than by changes in arousal or motivation or by direct effects on input and output processes. This may also be true for some complex cognitive tasks. However, the sparsity and diversity of experimental studies does not exclude the possibility of real and significant cognitive effects of vibration. Vibration may influence fatigue, but there is little relevant scientific evidence, and none which supports the complex form of the "fatigue-decreased proficiency limit" offered in International Standard 2631 (ISO 1974, 1985).

### ***Changes in Physiological Functions***

Changes in physiological functions occur when subjects are exposed to a novel whole-body vibration environment in laboratory conditions. Changes typical of a "startle response" (e.g., increased heart rate) normalize quickly with continuing exposure, whereas other reactions either proceed or develop gradually. The latter can depend on all characteristics of vibration including the axis, the magnitude of acceleration, and the kind of vibration (sinusoidal or random), as well as on further variables such as circadian rhythm and characteristics of the subjects (see Hasan 1970; Seidel 1975; Dupuis and Zerlett 1986). Changes of physiological functions under field conditions often cannot be related to vibration directly, since vibration is often acting together with other significant factors, such as high mental strain, noise and toxic substances.

Physiological changes are frequently less sensitive than psychological reactions (e.g., discomfort). If all available data on persistent physiological changes are summarized with respect to their first significant appearance depending on the magnitude and frequency of whole-body vibration, there is a boundary with a lower border around  $0.7 \text{ m/s}^2$  r.m.s. between 1 and 10 Hz, and rising up to  $30 \text{ m/s}^2$  r.m.s. at 100 Hz. Many animal studies have been performed, but their relevance to humans is doubtful.

### ***Neuromuscular changes***

During active natural motion, motor control mechanisms act as a feed-forward control that is constantly adjusted by additional feedback from sensors in muscles, tendons and joints. Whole-body vibration causes a passive artificial motion of the human body, a condition that is fundamentally different from the self-induced vibration caused by locomotion. The missing feed-forward control during whole-body vibration is the most distinct change of the normal physiological function of the neuromuscular system. The broader frequency range associated with whole-body vibration (between 0.5 and 100 Hz) compared to that for natural motion (between 2 and 8 Hz for voluntary movements, and below 4 Hz for locomotion) is a further difference that helps to explain reactions of the neuromuscular control mechanisms at very low and at high frequencies.

Whole-body vibration and transient acceleration cause an acceleration-related alternating activity in the electromyogram (EMG) of superficial back muscles of seated persons that requires a tonic contraction to be maintained. This activity is supposed to be of a reflex-like nature. It usually disappears completely if the vibrated subjects sit relaxed in a bent position. The timing of muscle activity depends on the frequency and magnitude of acceleration. Electromyographic data suggest that an increased spinal load can occur due to reduced muscular stabilization of the spine at frequencies from 6.5 to 8 Hz and during the initial phase of a sudden upward displacement. In spite of weak EMG activity caused by whole-body vibration, back muscle fatigue during vibration exposure can exceed that observed in normal sitting postures without whole-body vibration.

Tendon reflexes may be diminished or disappear temporarily during exposure to sinusoidal whole-body vibration at frequencies above 10 Hz. Minor changes of postural control after exposure to whole-body vibration are quite variable, and their mechanisms and practical significance are not certain.

### ***Cardiovascular, respiratory, endocrine and metabolic changes***

The observed changes persisting during exposure to vibration have been compared to those during moderate physical work (i.e., increases of heart rate, blood pressure and oxygen consumption) even at a vibration magnitude near to the limit of voluntary tolerance. The increased ventilation is partially caused by oscillations of the air in the respiratory system. Respiratory and metabolic changes may not correspond, possibly suggesting a disturbance of the respiration control mechanisms. Various and partially contradictory findings have been reported for changes of the adrenocorticotrophic hormones (ACTH) and catecholamines.

### ***Sensory and central nervous changes***

Changes of vestibular function due to whole-body vibration have been claimed on the basis of an affected regulation of posture, although posture is controlled by a very complex system in which a disturbed vestibular function can be largely compensated by other mechanisms. Changes of the vestibular function seem to gain significance for exposures with very low frequencies or those near the resonance of the whole body. A sensory mismatch between vestibular, visual and proprioceptive (stimuli received within the tissues) information is supposed to be an important mechanism underlying physiological responses to some artificial motion environments.

Experiments with short-term and prolonged combined exposures to noise and whole-body vibration, seem to suggest that vibration has a minor synergistic effect on hearing. As a tendency, high intensities of whole-body vibration at 4 or 5 Hz were associated with higher additional temporary threshold shifts (TTS). There was no obvious relation between the additional TTS and exposure time. The additional TTS seemed to increase with higher doses of whole-body vibration.

Impulsive vertical and horizontal vibrations evoke brain potentials. Changes of the function of the human central nervous system have also been detected using auditory evoked brain potentials (Seidel et al. 1992). The effects were influenced by other environmental factors (e.g., noise), the difficulty of the task, and by the internal state of the subject (e.g., arousal, degree of attention towards the stimulus).

## **Long-Term Effects**

### ***Spinal health risk***

Epidemiological studies have frequently indicated an elevated health risk for the spine in workers exposed for many years to intense whole-body vibration (e.g., work on tractors or earth-moving machines). Critical surveys of the literature have been prepared by Seidel and Heide (1986), Dupuis and Zerlett (1986) and Bongers and Boshuizen (1990). These reviews concluded that intense long-term whole-body vibration can adversely affect the spine and can increase the risk of low-back pain. The latter may be a secondary consequence of a primary degenerative change of the vertebrae and disks. The lumbar part of the vertebral column was found to be the most frequently affected region, followed by the thoracic region. A high rate of impairments of the cervical part, reported by several authors, seems to be caused by a fixed unfavourable posture rather than by vibration, although there is no conclusive evidence for this hypothesis. Only a few studies have considered the function of back muscles and found a muscular insufficiency. Some reports have indicated a significantly higher risk of the dislocation of lumbar disks. In several cross-sectional studies Bongers and Boshuizen (1990) found more low-back pain in drivers and helicopter pilots than in comparable reference workers. They concluded that professional vehicle driving and helicopter flying are important risk factors for low-back pain and back disorder. An increase in disability pensioning and long-term sick leave due to intervertebral disc disorders was observed among crane operators and tractor drivers.

Due to incomplete or missing data on exposure conditions in epidemiological studies, exact exposure-effect relationships have not been obtained. The existing data do not permit the substantiation of a no-adverse-effect level (i.e., safe limit) so as to reliably prevent diseases of the spine. Many years of exposure below or near the exposure limit of the current International Standard 2631 (ISO 1985) are not without risk. Some findings have indicated an increasing health risk with increased duration of exposure, although selection processes have made it difficult to detect a relation in the majority of studies. Thus, a dose-effect relationship cannot currently be established by epidemiological investigations. Theoretical considerations suggest marked detrimental effects of high peak loads acting on the spine during exposures with high transients. The use of an "energy equivalent" method to calculate a vibration dose (as in International Standard 2631 (ISO 1985)) is therefore questionable for exposures to whole-body vibration containing high peak accelerations. Different long-term effects of whole-body vibration depending on the vibration frequency have not been derived from epidemiological studies. Whole-body vibration at 40 to 50 Hz applied to standing workers through the feet was followed by degenerative changes of the bones of the feet.

In general, differences between subjects have been largely neglected, although selection phenomena suggest they may be of major importance. There are no clear data showing whether the effects of whole-body vibration on the spine depend on gender.

The general acceptance of degenerative disorders of the spine as an occupational disease is debated. Specific diagnostic features are not known which would permit a reliable diagnosis of the disorder as an outcome of exposure to whole-body vibration. A high prevalence of degenerative spinal disorders in non-exposed populations hinders the assumption of a predominantly occupational aetiology in individuals exposed to whole-body vibration. Individual constitutional risk factors that might modify vibration-induced strain are unknown. The use of a minimal intensity and/or a minimal duration of whole-body vibration as a prerequisite for the recognition of an occupational disease would not take into account the expected considerable variability in individual susceptibility.

### ***Other health risks***

Epidemiological studies suggest that whole-body vibration is one factor within a causative set of factors which contribute to other health risks. Noise, high mental strain and shift work are examples of important concomitant factors which are known to be associated with health disorders. The results of investigations into disorders of other bodily systems have often been divergent or have indicated a paradoxical dependence of the prevalence of pathology on the magnitude of whole-body vibration (i.e., a higher prevalence of adverse effects with a lower intensity). A characteristic complex of symptoms and pathological changes of the central nervous system, the musculo-skeletal system and the circulatory system has been observed in workers standing on machines used for the vibro-compression of concrete and exposed to whole-body vibration beyond the exposure limit of ISO 2631 with frequencies above 40 Hz (Rumjancev 1966). This complex was designated as "vibration disease".

Although rejected by many specialists, the same term has sometimes been used to describe a vague clinical picture caused by long-term exposure to low-frequency whole-body vibration which, allegedly, is manifested initially as peripheral and cerebral vegeto-vascular disorders with a non-specific functional character. Based on the available data it can be concluded that different physiological systems react independently of one another and that there are no symptoms which might serve as an indicator of pathology induced by whole-body vibration.

**Nervous system, vestibular organ and hearing.** Intense whole-body vibration at frequencies higher than 40 Hz can cause damage and disturbances of the central nervous system. Conflicting data have been reported on effects of whole-body vibration at frequencies below 20 Hz. In some studies only, an increase of non-specific complaints such as headache and increased irritability has been found. Disturbances of the electroencephalogram (EEG) after long-term exposure to whole-body vibration have been claimed by one author and denied by others. Some published results are consistent with a decreased vestibular excitability and a higher incidence of other vestibular disturbances, including dizziness. However, it remains doubtful whether there are causal links between whole-body vibration and changes in the central nervous system or vestibular system because paradoxical intensity-effect relationships were detected.

In some studies, an additional increase of the permanent threshold shifts (PTS) of hearing has been observed after a combined long-term exposure to whole-body vibration and noise. Schmidt (1987) studied drivers and technicians in agriculture and compared the permanent threshold shifts after 3 and 25 years on the job. He concluded that whole-body vibration can induce an additional significant threshold shift at 3, 4, 6 and 8 kHz, if the weighted acceleration according to International Standard 2631 (ISO 1985) exceeds  $1.2 \text{ m/s}^2$  r.m.s. with a simultaneous exposure to noise at an equivalent level of more than 80 decibels (dBA).

**Circulatory and digestive systems.** Four main groups of circulatory disturbances have been detected with a higher incidence among workers exposed to whole-body vibration:

1. peripheral disorders, such as the Raynaud-syndrome, near to the site of application of whole-body vibration (i.e., the feet of standing workers or, with a low degree only, the hands of drivers)
2. varicose veins of the legs, haemorrhoids and varicocele
3. ischaemic heart disease and hypertension
4. neurovascular changes.

The morbidity of these circulatory disturbances did not always correlate with the magnitude or duration of vibration exposure. Although a high prevalence of various disorders of the digestive system has often been observed, almost all authors agree that whole-body vibration is but one cause and possibly not the most important.

**Female reproductive organs, pregnancy and male urogenital system.** Increased risks of abortions, menstrual disturbances and anomalies of positions (e.g., uterine descent) have been assumed to be associated with long-term exposure to whole-body vibration (see Seidel and Heide 1986). A safe exposure limit in order to avoid a higher risk for these health risks cannot be derived from the literature. The individual susceptibility and its temporal changes probably co-determine these biological effects. In the available literature, a harmful direct effect of whole-body vibration on the human foetus has not been reported, although some animal studies suggest that whole-body vibration can affect the foetus. The unknown threshold value for adverse effects on pregnancy suggests a limitation on an occupational exposure to the lowest reasonable extent.

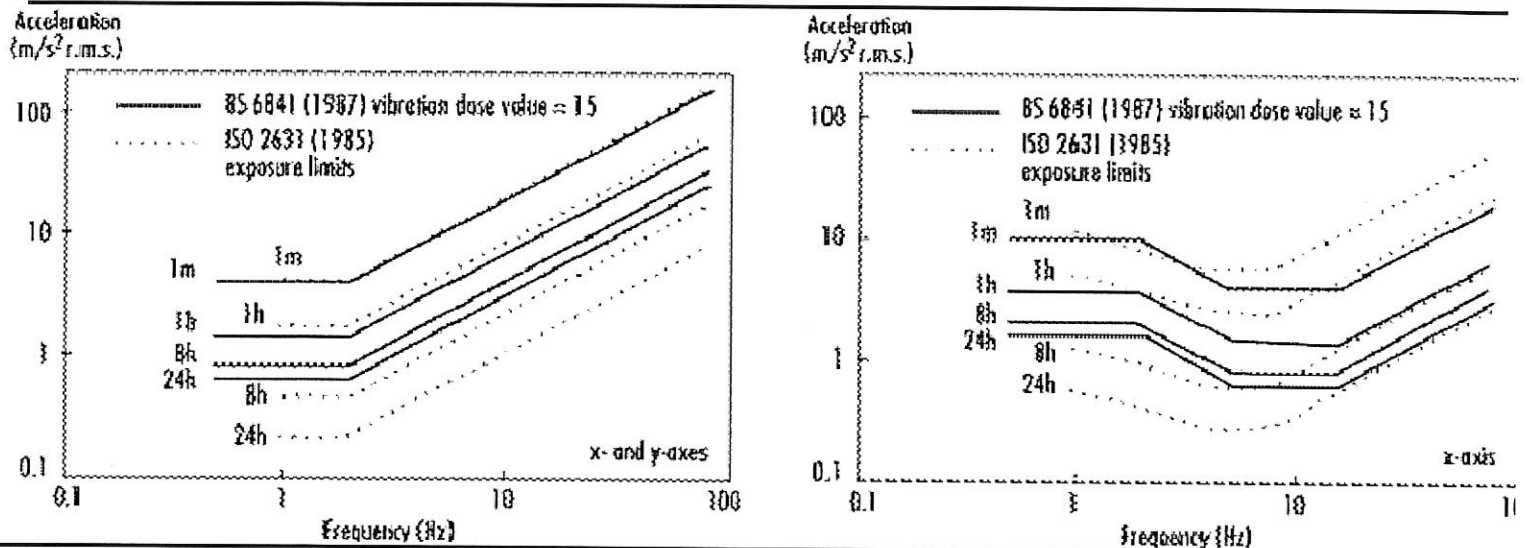
Divergent results have been published for the occurrence of diseases of the male urogenital system. In some studies, a higher incidence of prostatitis was observed. Other studies could not confirm these findings.

### **Standards**

No precise limit can be offered to prevent disorders caused by whole-body vibration, but standards define useful methods of quantifying vibration severity. International Standard 2631 (ISO 1974, 1985) defined exposure limits (see figure 50.1) which were "set at approximately half the level considered to be the threshold of pain (or limit of voluntary tolerance) for healthy human subjects". Also shown in figure 50.1 is a vibration dose value action level for vertical vibration derived from British Standard 6841 (BSI 1987b); this standard is, in part, similar to a draft revision of the International Standard.

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Figure 50.1 Frequency dependencies for human response to whole-body vibration

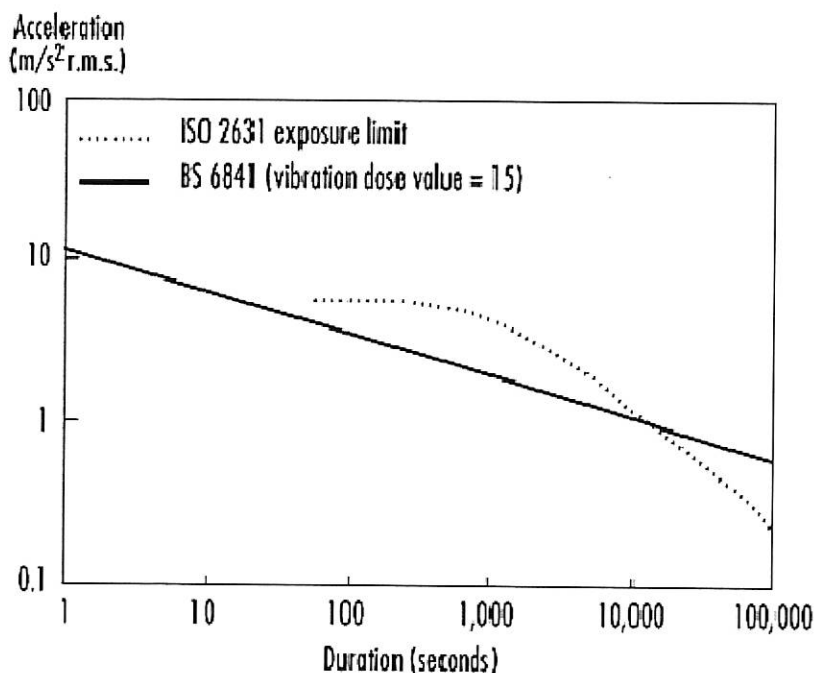


The vibration dose value can be considered to be the magnitude of a one-second duration of vibration which will be equally severe to the measured vibration. The vibration dose value uses a fourth-power time dependency to accumulate vibration severity over the exposure period from the shortest possible shock to a full day of vibration (e.g., BSI 6841):

$$\text{Vibration dose value} = \left[ \int_{t=0}^{t=\infty} a(t)^4 dt \right]^{\frac{1}{4}}$$

The vibration dose value procedure can be used to evaluate the severity of both vibration and repetitive shocks. This fourth-power time dependency is simpler to use than the time dependency in ISO 2631 (see figure 50)

Figure 50.2 Time dependencies for human response to a whole-body vibration



British Standard 6841 offers the following guidance.

High vibration dose values will cause severe discomfort, pain and injury. Vibration dose values also indicate, in a general way, the severity of the vibration exposures which caused them. However there is currently no consensus of opinion on the precise relation between vibration dose values and the risk of injury. It is known that vibration magnitudes and durations which produce vibration dose values in the

region of  $15 \text{ m/s}^{1.75}$  will usually cause severe discomfort. It is reasonable to assume that increased exposure to vibration will

be accompanied by increased risk of injury (BSI 1987b).

At high vibration dose values, prior consideration of the fitness of the exposed persons and the design of adequate safety precautions may be required. The need for regular checks on the health of routinely exposed persons may also be considered.

The vibration dose value provides a measure by which highly variable and complex exposures can be compared. Organizations may specify limits or action levels using the vibration dose value. For example, in some countries, a vibration dose value of  $15 \text{ m/s}^{1.75}$  has been used as a tentative action level, but it may be appropriate to limit vibration or repeated shock exposures to higher or lower values depending on the situation. With current understanding, an action level merely serves to indicate the approximate values that might be excessive. Figure 50.2 illustrates the root-mean-square accelerations corresponding to a vibration dose value of  $15 \text{ m/s}^{1.75}$  for exposures between one second and 24 hours. Any exposure to continuous vibration, intermittent vibration, or repeated shock may be compared with the action level by calculating the vibration dose value. It would be unwise to exceed an appropriate action level (or the exposure limit in ISO 2631) without consideration of the possible health effects of an exposure to vibration or shock.

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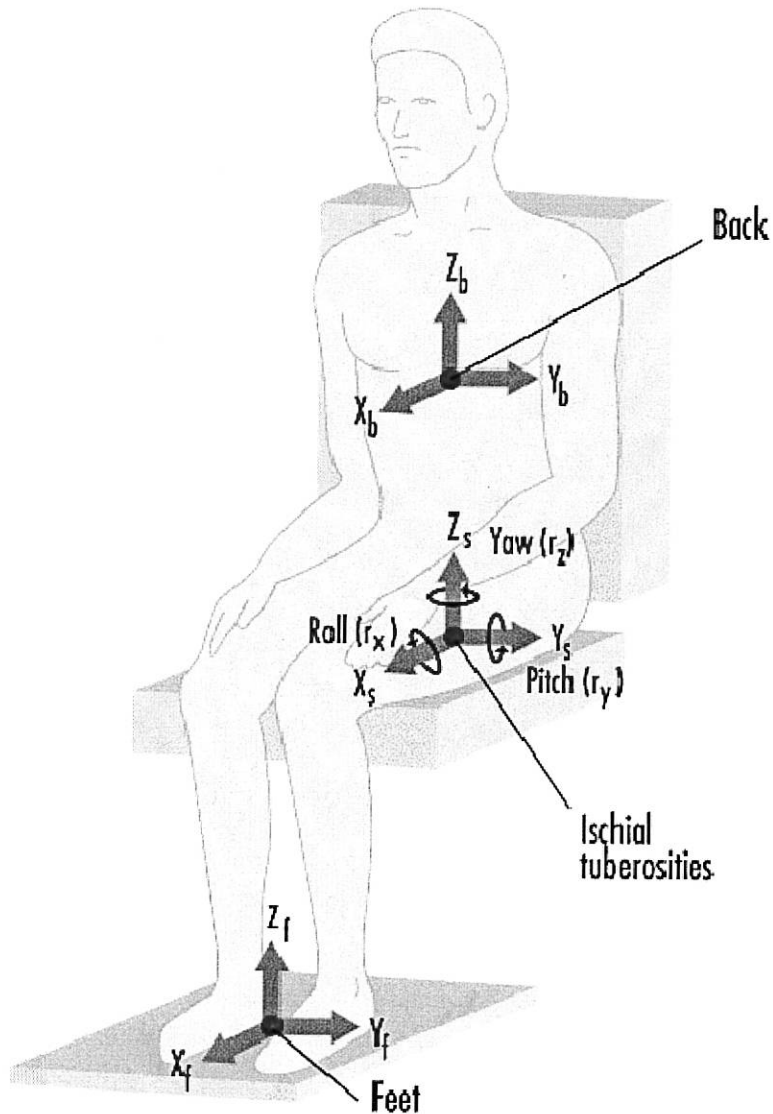
The ***Machinery Safety Directive*** of the European Economic Community states that machinery must be designed and constructed so that hazards resulting from vibration produced by the machinery are reduced to the lowest practicable level, taking into account technical progress and the availability of means of reducing vibration. The ***Machinery Safety Directive*** (Council of the European Communities 1989) encourages the reduction of vibration by means additional to reduction at source (e.g., good seating).

### **Measurement and Evaluation of Exposure**

Whole-body vibration should be measured at the interfaces between the body and the source of vibration. For seated persons this involves the placement of accelerometers on the seat surface beneath the ischial tuberosities of subjects. Vibration is also sometimes measured at the seat back (between the backrest and the back) and also at the feet and hands (see figure 50.3).

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*Figure 50.3 Axes for measuring vibration exposures of seated persons*



Epidemiological data alone are not sufficient to define how to evaluate whole-body vibration so as to predict the relative risks to health from the different types of vibration exposure. A consideration of epidemiological data in combination with an understanding of biodynamic responses and subjective responses is used to provide current guidance. The manner in which the health effects of oscillatory motions depend upon the frequency, direction and duration of motion is currently assumed to be the same as, or similar to, that for vibration discomfort. However, it is assumed that the total exposure, rather than the average exposure, is important, and so a dose measure is appropriate.

In addition to evaluating the measured vibration according to current standards, it is advisable to report the frequency spectra, magnitudes in different axes and other characteristics of the exposure, including the daily and lifetime exposure durations. The presence of other adverse environmental factors, especially sitting posture, should also be considered.

## Prevention

Wherever possible, reduction of vibration at the source is to be preferred. This may involve reducing the undulations of the terrain or reducing the speed of travel of vehicles. Other methods of reducing the transmission of vibration to operators require an understanding of the characteristics of the vibration environment and the route for the transmission of vibration to the body. For example, the magnitude of vibration often varies with location: lower magnitudes will be experienced in some areas. Table 50.2 lists some preventive measures that may be considered.

**Table 50.2**  
**Summary of preventive measures to consider when persons**  
**are exposed to whole-body vibration**

Group	Action
Management	<ul style="list-style-type: none"> <li>Seek technical advice</li> <li>Seek medical advice</li> <li>Warn exposed persons</li> <li>Train exposed persons</li> <li>Review exposure times</li> <li>Have policy on removal from exposure</li> </ul>
Machine manufacturers	<ul style="list-style-type: none"> <li>Measure vibration</li> <li>Design to minimize whole-body vibration</li> <li>Optimize suspension design</li> <li>Optimize seating dynamics</li> <li>Use ergonomic design to provide good posture etc.</li> <li>Provide guidance on machine maintenance</li> <li>Provide guidance on seat maintenance</li> <li>Provide warning of dangerous vibration</li> </ul>
Technical-at workplace	<ul style="list-style-type: none"> <li>Measure vibration exposure</li> <li>Provide appropriate machines</li> <li>Select seats with good attenuation</li> <li>Maintain machines</li> <li>Inform management</li> </ul>
Medical	<ul style="list-style-type: none"> <li>Pre-employment screening</li> <li>Routine medical checks</li> <li>Record all signs and reported symptoms</li> <li>Warn workers with apparent predisposition</li> <li>Advise on consequences of exposure</li> </ul>
Exposed persons	<ul style="list-style-type: none"> <li>Inform management</li> <li>Use machine properly</li> <li>Avoid unnecessary vibration exposure</li> <li>Check seat is properly adjusted</li> <li>Adopt good sitting posture</li> <li>Check condition of machine</li> <li>Inform supervisor of vibration problems</li> <li>Seek medical advice if symptoms appear</li> <li>Inform employer of relevant disorders</li> </ul>

Source: Adapted from Griffin 1990.

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Seats can be designed to attenuate vibration. Most seats exhibit a resonance at low frequencies, which results in higher magnitudes of vertical vibration occurring on the seat than on the floor! At high frequencies there is usually attenuation of vibration. In use, the resonance frequencies of common seats are in the region of 4 Hz. The amplification at resonance is partially determined by the damping in the seat. An increase in the damping of the seat cushioning tends to reduce the amplification at resonance but increase the transmissibility at high frequencies. There are large variations in transmissibility between seats, and these result in significant differences in the vibration experienced by people.

A simple numerical indication of the isolation efficiency of a seat for a specific application is provided by the seat effective amplitude transmissibility (SEAT) (see Griffin 1990). A SEAT value greater than 100% indicates that, overall, the vibration on the seat is worse than the vibration on the floor. Values below 100% indicate that the seat has provided some useful attenuation. Seats should be designed to have the lowest SEAT value compatible with other constraints.

A separate suspension mechanism is provided beneath the seat pan in suspension seats. These seats, used in some off-road vehicles, trucks and coaches, have low resonance frequencies (around 2 Hz) and so can attenuate vibration at frequencies above about 3 Hz. The transmissibilities of these seats are usually determined by the seat manufacturer, but their isolation efficiencies vary with operating conditions.

Measurements of vibration for full working shifts were made on three articulated heavy goods vehicles (HGVs). Acceleration measurements in the vehicles were made on the surface of and at the base of the drivers' seats. Measurements were obtained from two tri-axial ICP accelerometers to obtain vibration measurements at the floor beneath the driver's seat and on the seat in the x-, y- and z- axes. Tri-axial vibration on the driver's seat was measured by placing a semi-rigid mounting disc incorporating the accelerometer on the seat.

The signals from the accelerometers were conditioned using two Larson Davis Human Vibration Meters, type HVM 100. These meters logged the vibration every 10 seconds for the duration of the shift. Data were also acquired to a stand-alone data logger (Logbook 300) at 256 samples/s for the duration. The data reported in this paper only correspond to the measurements made using the HVM100 meters. Speed was logged using a Garmin GPS logger. Measurements were carried out for the full duration of the vehicle operator's working day or journey where appropriate. Vibration magnitudes measured on the base and surface of the seats for truck 1 are shown in Figure 1. The general pattern of vibration exposure was similar on the seat and at the base of the seat.

Attachment No. 4

Occupational Health Clinics for Ontario Workers Inc.

Whole Body Vibration

**Occupational Health Clinics for Ontario Workers Inc.**

**W H O L E B O D Y V I B R A T I O N**

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W H O L E B O D Y V I B R A T I O N Occupational Health Clinics for Ontario Workers Inc.

Our bodies are exposed to vibration at work from many machines, such as construction machinery (*bulldozers, towmotors, forklifts and cranes*), heavy equipment (*grinders, jack hammers*), and power hand tools. Vibration has been proven to result in musculoskeletal disorders of both the hand and arm, the neck, and the back. There are two types of occupational vibration: segmental and whole body. Segmental vibration is transmitted through the hands and arms, and is known to cause specific health effects such as Reynaud's syndrome.

Whole body vibration is transmitted through the body's supporting surfaces such as the legs when standing and the back and buttocks when sitting. Along with musculoskeletal problems, exposure to occupational whole body vibration also presents a health risk to the psychomotor, physiological, and psychological systems of the body.

#### Whole Body Vibration Exposure

Whole body vibration is transmitted to the body through the supporting surfaces such as the feet, buttocks or back. There are various sources of whole body vibration such as standing on a vibrating platform, floor surface, driving, and construction, manufacturing, and transportation vehicles. The health effects of whole body vibration on drivers of heavy vehicle versus workers in a similar environment who were not exposed to whole body vibration have been compared. Research indicates back disorders are more prevalent and more severe in exposed to vibration versus non-exposed workers.

With short term exposure to vibration in the 2-20 Hz range at 1 m/sec<sup>2</sup>, one can feel several different symptoms:

- Abdominal pain
- General feeling of discomfort, including headaches
- Chest pain
- Nausea
- Loss of equilibrium (*balance*)
- Muscle contractions with decreased performance in precise manipulation tasks
- Shortness of breath
- Influence on speech

Long-term exposure can cause serious health problems, particularly with the spine:

- disc displacement
- degenerative spinal changes
- lumbar scoliosis
- intervertebral disc disease
- degenerative disorders of the spine
- herniated discs
- disorders of the gastrointestinal system
- uro-genital systems

#### MEASURING THE RISK FROM WHOLE BODY VIBRATION

Human response to whole body vibration depends on the frequency of vibration, acceleration (or magnitude) of the vibration, and how long a person is exposed to the vibration. Because of the difficulty of evaluating the response to vibration and inconsistencies in quantitative data obtained from research, the International Standards Organization (ISO) 2631/1, Evaluation of human exposure to whole body vibration, has been established. When using these criteria and limits, it is important to bear in mind the restrictions placed upon their application. Some research indicates that the standards are not low enough and that musculoskeletal disorders are caused from exposure to vibration levels below the standard.

This standard is applicable only to situations involving people of normal health: that is persons who are considered fit to carry out normal living routines, including travel, and to undergo the stress of a typical working day or shift. The standard provides numerical limits for exposure to vibrations transmitted from solid surfaces to the human body in the frequency range of 1 to 80 Hz.

The standard addresses three different levels of concern: Reduced Comfort, Fatigue Decreased Proficiency, and Exposure Limits.

1. Reduced Comfort Boundary is applicable where passenger comfort is of concern, for instance on

trains, subways, and buses. This limit will not be addressed here.

2. Fatigue Decreased Proficiency Boundary is applied to the situations where maintaining operator efficiency of a vehicle is of concern, such as situations where operators are required to work with safe manipulation of controls or to read the gauges accurately.

3. Exposure Limit applies to situations where the health and safety of the worker, such as back injuries and injuries to internal organs, is of concern.

#### Industry

Manufacturing

Construction

Transportation

Agriculture

#### Vehicles

Forklifts

Power shovels, towmotors, cranes,  
wheel loaders, bulldozers, caterpillars,  
earth moving machinery

Buses, helicopters, subway trains, locomotives,  
trucks (*tractor/trailer*)

Tractors

#### HOW TO DETERMINE EXPOSURE LIMIT

~~If the measured acceleration is in the vertical direction use graph 1, otherwise use graph 2.~~ Studies have found that the resonance frequency-range of the lower back is 4–8 Hz. Given this information and the measured acceleration value at work, an exposure work time and acceleration limit can be determined. For example, the limit to whole-body vibration acceleration (~~vertical direction graph 1~~) allowed for an 8 hours working day is  $0.315 \text{ m/s}^2$  if fatigue-decreased proficiency is the criterion and  $0.63 \text{ m/s}^2$  if health is the criterion (*exposure limit*).

Several studies have published vibration levels for various vehicles used in the construction, manufacturing and farming industries. ~~These values are summarized below in order to compare them to the ISO Fatigue-Decreased Proficiency Boundary and Exposure Limits.~~ Some of the vibration values were measured on various terrain types. Most values, however, did not take into account the maintenance level, age of vehicle, and other contributing factors. Thus, caution should be taken when using the value.

#### CONTRIBUTING FACTORS TO THE VIBRATION MAGNITUDE

Although a new piece of machinery may expose workers to vibration levels within the ISO standards, several other factors influence the actual whole body vibration exposure magnitudes. The actual whole body vibration magnitude to which a worker is exposed is affected by vehicle maintenance, the terrain travelled, seat design, and other vibrating equipment on the vehicle. Whole cause of back disorders occurring to drivers of heavy machinery. The prolonged awkward sitting postures often required by drivers also affects back health. Drivers are often required to drive backwards or view to the side of the vehicle thus adopting twisted postures.

Drivers work in these awkward sitting postures for prolonged periods of time often between 6 and 14 hours depending on shift schedules. Awkward postures combined with repetition/duration and/or forceful exertions are considered risk factors for the development of musculoskeletal disorders. Furthermore, poor ergonomic designs of cabs, seats and inaccessible control gear (*pedals, steering wheel*) will affect the musculoskeletal health of a worker.

## RECOMMENDATIONS TO REDUCE THE EFFECTS OF WHOLE BODY VIBRATION

1. Reduce the transmission of vibration to the worker by engineering the equipment or workplace more effectively. For example:

- improving vehicle suspension
- altering the position of the seat within the vehicle
- mount equipment on springs or compression pads
- maintain equipment properly (*i.e., balance and replace worn parts*)
- proper engineering of seating
- use materials that generate less vibration

2. Decrease the amount of vibration to which the driver is exposed by:

- reducing the speed of travel
- minimizing the exposure period by alternating working tasks where vibration is present and those where it is negligible
- increasing rest/recovery time between exposures.

3. Modify the seat and control positions to reduce the incidence of forward or sideways leaning of the trunk, and provide back rest support.

4. Eliminate awkward postures due to difficulty of seeing displays or reaching control.

5. Where feasible, reduce or isolate workers from the vibration source. For example:

- in seated tasks, provide a spring or cushion as a vibration isolator
- in standing operations, provide a rubber or vinyl floor mat
- minimize the undulations of the surface over which the vehicle must travel.

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Attachment No. 5

**The elastic and damping properties  
Of magneto-rheological elastomers**

**Market Kellie**

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## Abstract

Magneto rheological elastomers (MREs) belong to the group of so-called smart materials, which respond to an external stimulus by changing their viscoelastic properties. Magnetorheological (MR) material can be fluid, gel or solid material like elastomer. The mechanical properties of the MR materials change when subjected to an external magnetic field. The MREs are interesting candidates for the active stiffness and vibration control of structural systems.

The aim of this study was to increase the knowledge on the mechanical and viscoelastic properties of isotropic and aligned MREs. The focus was to clarify the changes in the elastic and vibration damping properties of both studied types of MREs when subjected to magnetic field. Another aim was to study the influence of the alignment of the magnetic particles on the composite properties with and without applied magnetic field.

Isotropic and aligned MREs were prepared from silicone elastomer matrix with varying carbonyl iron content. The MREs were tested in bending and compression modes with sinusoidal dynamic loading. The 3-point bending experiments were carried out using a dynamic mechanical analyzer (DMA) in resonance for both isotropic and aligned MREs where the filler content varied from 0 to 30 vol.%. For characterizing the materials in compression with applied magnetic field, a special coil device was designed. Isotropic and aligned MREs with 30 vol.% of Fe were also characterized in dynamic compression with varying frequencies and strain amplitudes. The spring constant, elastic/shear modulus and damping ratio/loss factor values were calculated on the basis of the measured data with and without applied magnetic field.

The stiffness and damping properties of both isotropic and aligned MREs can be modified by applying external magnetic field. In isotropic MREs the stiffness and damping increase in the magnetic field if the filler volume fraction exceeds 15 %. The damping also increases with the increasing volume fraction of iron and it has a maximum value at 27 vol.% when measured with applied magnetic field. The damping and stiffness properties of aligned MREs depend on the mutual directions of load, magnetic field and the particle alignment in the composite. If the dynamic load in bending or in compression is applied in the direction of the particle chains, the damping is initially high and the increasing magnetic field strength has only small influence on damping. In this case, dynamic stiffness is also high and can be increased by applying the magnetic field. If the external load is applied so that the deformation is concentrated in the areas between the particle chains, the damping is initially comparable to that of isotropic MREs and can be increased in the magnetic field. In this case the dynamic stiffness is quite low and applied magnetic field does not increase it significantly.

The particle network structure of aligned MREs has a significant influence on the elastic and damping properties of the composite material. Inside the chains the effective filler content is higher than the average filler content. This is due to the trapped elastomer captured between the particles and to the formation of the third phase (elastomer shell) in the immediate vicinity of the filler particle. By optimizing the particle density and alignment, either the stiffness or the damping of MREs can be increased by applying the magnetic field.